

Performance and Degradation Analysis of Poly-Crystalline PV Modules Installed In Tropical Conditions

¹ **P.Greeshma**, ² **N. Ramchander**

¹M Tech Scholar, ²Sr.Assistant Professor

Department of Electrical and Electronics Engineering

BVRIT, Narsapur, Telangana, India

Corresponding Author: chandrababu.p@bvr.it.ac.in, rapideet16@gmail.com

Abstract

In this paper practical field performance of poly-crystalline solar photovoltaic (PV) modules was studied and presents the correlation between efficiency, temperature and degradation rate of modules as per STC conditions, which are installed at rooftop of the Department of Electrical Engineering BVRIT. The nominal output power of the PV module considered for the study is 240Wp and the panel is composed of 60 cells in a 10×6 matrix connected in series. After few operation years under tropical environment the degradation rate of electrical characteristics such as I-V and P-V curves, open-circuit voltage (Voc), short-circuit current (Isc), maximum output current (Imax), maximum output voltage (Vmax), maximum power output (Pmax) and fill factor (FF) are evaluated at standard test conditions (STC). Through this study, it has noticed that the efficiency of solar panel is linearly inversely proportional to temperature and degradation rate in a linear fashion.

Keywords: Open-Circuit Voltage; Short-Circuit Current; Maximum Output Voltage; Maximum Power Output; Fill Factor; Efficiency; Degradation Rate

I. INTRODUCTION

Practical field study of performances of three identical monocrystalline solar modules, single power of 60 W, with different inclinations (horizontal, optimally inclined oriented toward South and vertically oriented toward South) in real meteorological conditions, in Nis, Serbia are presented. The efficiency, performance ratio and fill factors are measured and compared [1].

Two identical BP-SX320 panels with polycrystalline-silicon cells with nominal

output power of 20W and each of the panels is comprised of 36 cells in a 4x9 matrix connected in series. The efficiency of the solar panel is inversely proportional to temperature in a linear fashion and the decrease rate of efficiency per temperature increase is determined as 0.0024(%/°C) [2].

The effects of temperature and radiation intensity on the parameters of a copper indium diselenide (CIS) photovoltaic module. An outdoor experimental setup is installed to carry out a series of I-V curve measurements under different irradiance and tem-

perature conditions for the module [3].

NREL study suggests that a more reasonable thumb of rule will be degradation less than 0.5% per year. The quality of module is of immense importance. It is safe to assume no degradation for the first three years and then a maximum of 0.5% per year over the life of modules [4].

In this paper the performance of a single polycrystalline PV module is studied under outdoor (tropical condition) installation. The performance parameters include the efficiency and degradation rate of module. Here the study period is considered from April 2013 to June 2015. By considering open circuit voltage (V_{oc}), short circuit current (I_{sc}), solar irradiance and module temperature, the degradation rate of polycrystalline module is calculated. The irradiance is measured using the Pyranometer. To measure the temperature; temperature sensors are attached at the bottom of the solar panel which is further connected to the data logger. This data logger is connected to the personal computer where every instant data is stored.

II. SYSTEM DESCRIPTION

A. System installation

An 8.4kWp grid connected solar PV plant is installed on the rooftop of department of Electrical and Electronics engineering, B.V.Raju institute of engineering and technology. This plant was installed on February 2012 with an experimental setup with all measuring instruments such as Pyranometer, temperature sensor, data logger, I-V curve tracer, thermal imaging camera for hot spot detection and data storing system equipment. The plant is being protected by the lightening arrestor and voltage surge switch. In this paper a single PV module performance is examined from 8.4kWp solar PV plant setup.

B. Panel specifications

The nominal output power of the considered polycrystalline module is 240Wp and each of the panel is compressed of 60cells. The PV module is arranged with south facing and it is a fixed plane tilt of 17° and azimuth 0° (Hyderabad). The considered solar panel specifications are shown in table 1.

C. I-V curve tracer

The Daystar (DS-100C) I-V curve tracer is a portable self-contained unit for testing

photovoltaic systems. Figure 1 shows the DS-100C I-V curve tracer. I-V curve tracers capture the data set that includes the I-V curve data plus values of open circuit voltage (V_{oc}), and short circuit current (I_{sc}), peak power, voltage at peak power (V_{pk}), current at peak power (I_{pk}), and fill factor which are calculated and displayed with the curve. These obtained values are uniquely capable of identifying symptoms of underperformance in PV systems [5].

TABLE 1: PANEL SPECIFICATIONS

Type	Polycrystalline
Rated power	240Wp
Module efficiency at STC	14.3%
Open circuit voltage V_{OC}	37.56V
Short circuit voltage I_{SC}	8.44A
Rated voltage V_{MPP}	30.23V
Rated current I_{MPP}	7.94A
Power tolerance	$\pm 2.5\%$



Fig. 1. DS I-V curve tracer

III. THEORETICAL DATA

Performance characteristics of solar PV module are Short circuit current (I_{sc}), Open-Circuit Voltage (V_{oc}), Fill (FF), Solar Cell Efficiency (η), Degradation Rate (δ), Performance Ratio (PR). These characteristics are discussed below,

A. Short Circuit Current (I_{sc})

Short circuit current is the light-generated current or photo current, I_L . It is the current in the circuit when the load is zero in the circuit. It can be achieved by connecting the positive and negative terminals by copper wire [6].

$$I = I_0 \left[\exp \left(\frac{eV}{kT} \right) - 1 \right] - I_L$$

value of the fill factor is one, which is not possible.

$$FF = \frac{P_{max}}{(V_{oc} \times I_{sc})} = \frac{(I_{max} \times V_{max})}{(V_{oc} \times I_{sc})} \quad (2)$$

D. Solar Cell Efficiency (η)

Efficiency of the considered PV module at standard test conditions is 14.3% but its value varies when it is placed under outdoor conditions. The input for calculating efficiency is the product of area of module (1.67 sq. meters) and input incident irradiance on the module which is at a tilt of 17° . The output is the maximum power (P_{max}) obtained.

$$\eta = \frac{I_{max} \times V_{max}}{(\text{Incident solar radiation}(G) \times \text{Area of solar cell}(A_c))} \quad (1) \quad (3)$$

B. Open-Circuit Voltage (V_{oc})

The open-circuit voltage, V_{oc} , is the maximum voltage available from a solar cell, and this occurs at zero current. The open-circuit voltage corresponds to the amount of forward bias on the solar cell due to the bias of the solar cell junction with the light-generated current.

C. Fill Factor (FF)

The fill factor is defined as the ratio of the maximum power from the solar cell to theWhere I_{max} and V_{max} are the current and voltage for maximum power, corresponding to solar intensity (G),[6].

E. Degradation Rate (δ)

Photovoltaic (PV) module degradation rate analysis quantifies the loss of PV power output over time and is useful for estimating the impact of degradation on the cost of energy.

Product of V_{oc}

And I_{sc} . The maximum

δ : Decline in efficiency per temperature degree (% / °C).

F. Performance Ratio (PR)

Performance ratio is the ratio of the actual and theoretically possible energy outputs. It is largely independent of the orientation of a PV plant and the incident solar irradiation on the PV plant. For this reason, the performance ratio can be used to compare PV plants supplying the grid at different locations all over the world.

$$\text{Performance ratio} = \frac{\text{Actual energy generated under field conditions}}{\text{Energy estimated without temperature losses}}$$

G. Normalized Power (P_{norm})

Equation 6 shows normalized power calculation of PV plant. Rated power output of panel is 240Wp.Irradiance at STC is 1000 W/m².

$$\delta = \frac{\eta_{STC} - \eta_{field}}{T_{field} - T_{STC}} \quad (4)$$

$$\text{Normalized Power (P}_{\text{norm}}\text{)} = \frac{\text{Rated power output} \times \text{Radiation} \times (1 - 0.0035[\text{cell temperature} - 25^\circ\text{C}])}{\text{Rated irradiance}}$$

IV. PRACTICAL DATA

The considered experimental time period is from April 2012 to June 2015. The table 2 consists of performance parameters i.e., temperature of the module (T), solar irradiance (G), open circuit voltage (V_{oc}), short circuit current (I_{sc}) and Fill factor (FF). Table 3 consists of Maximum

power output (P_{mpp}), Normalized output power (P_{norm}) efficiency (η) and degradation rate

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A. Performance characteristics calculation

This section involves the performance characteristics calculation of the PV module (efficiency and degradation rate) by considering the onsite obtained temperature and irradiance (POA).

TABLE 2: PERFORMANCE CHARACTERISTICS OF PV MODULE

Month/Year	T	G	V_{oc}	I_{sc}	FF
April-12	56.2	949	33.02	8.423	69.1
May-12	46.3	751	33.73	7.024	71.3
June-12	53.8	778	33.71	7.082	71.3
July-12	43	881	34.88	7.672	71.9
September-12	49.1	1031	33.88	8.634	70.3
November-12	54.5	946	33.66	7.638	70.6
October-13	52	991	34.01	7.989	70.9

November-13	59	984	33.39	7.943	70.4
December-13	49.4	980	34.44	7.751	71.4
February-14	63.2	1028	32.60	8.478	68.6
April-14	55	763	33.26	6.282	71.5
September-14	62	1028	32.78	8.585	68.3
October-14	51.8	1040	33.37	8.38	67.8
December-14	53.8	1011	33.86	8.041	68.2
January-15	56.1	1103	33.64	8.869	67.5
February-15	60	1067	33.40	8.429	67.3
April-15	64	953	32.39	8.169	65.8
June-15	52.9	834	33.83	6.844	67.7

Where

$$\times 100 = 14.3\%$$

$$T - \text{Cell temperature } (^{\circ}\text{C})_{\eta} = \frac{240}{(1000 \times 1.67)}$$

G – Solar irradiance

(W/m²) V_{oc} – Open cir-

cuit Voltage (V) I_{sc} –

Short circuit Current (A)

FF- Fill Factor (%)

Practical data for determining field performance characteristics of PV module as shown in table 2, which are obtain from I-V curve tracer during the study period.

i. Efficiency at STC

The solar cell power conversion efficiency can be given as the ratio of P_{max} and P_{in}

ii. Degradation rate

The degradation rate of the module during April 2012 is considered with an efficiency of 12.12, module temperature is 56.2 °C and the irradiance at that instant is 949 W/m².

$$\delta = \frac{\eta_{\text{STC}} - \eta_{\text{field}}}{T_{\text{field}} - T_{\text{STC}}} = \frac{14.3 - 12.12}{56.2 - 25} = 0.069\% / ^{\circ}\text{C} \quad (8)$$

iii. Normalized Power (P_{norm})

P_{norm} of April 2012 is
With calculation below.

$$\eta = \frac{P_{\text{max}}}{(\text{Incident solar radiation (G)} \times \text{Area of solar cell})} \quad (7)$$

Normalized P

TABLE 3 CALCULATED RESULTS

Month/Year	P_{Mpp}	P_{norm}	η	δ
April-12	192.1	202.88	12.12	0.069
May-12	169	166.80	13.47	0.039
June-12	170.2	167.89	13.09	0.042
July-12	192.4	198.11	13.07	0.068
September-12	205.5	226.56	11.93	0.098
November-12	181.7	203.59	11.5	0.095
October-13	192.8	215.36	11.64	0.098
November-13	186.8	208.05	11.36	0.086
December-13	190.7	215.11	11.65	0.011
February-14	189.5	213.73	11.03	0.085
April-14	149.3	163.89	11.71	0.086
September-14	192.2	214.76	11.19	0.084
October-14	189.6	226.18	10.91	0.126
December-14	185.8	218.18	11	0.114
January-15	201.5	235.90	10.94	0.108
February-15	189.5	224.71	10.63	0.104
April-15	147.2	197.49	10.94	0.086
June-15	156.8	180.61	11.15	0.11

Where	o
P	r
M	m
p	—
p	
—	N
	o
	r
M	m
a	a
x	l
i	i
m	z
u	e
m	d
p	p
o	o
w	w
e	e
r	r
o	(
u	W
t	)
p	η – Efficiency (%)
u	δ – Degradation Rate (%/°C)
t	Table 3 shows practical values of
	Maximum power output (W), Nor-
(	malized output Power (W), efficien-
W	cy (%) and degradation rate (%/°C).
)	September 2012 has output power of
	205.5 W, Maximum efficiency of
P	13.47% is recorded in May 2012,
n	

degradation rate is low in December 2013 it is $0.011\%/^{\circ}\text{C}$.

V. RESULTS AND DISCUSSION

The Fig.2 explains about the decrease in the efficiency with time. The efficiency during April 2012 is 12.12% and on June 2015 the efficiency is 11.15% . The linear trend line gives a practical decrease in the efficiency when the panel is placed in outdoor conditions.

The Fig.3 gives a clear view of degradation rate of the panel when it is exposed in outdoor conditions. The linear line explains the increase of the degradation rate in the considered period. The degradation value on April 2012 is $0.069\%/^{\circ}\text{C}$ and on June 2015 is $0.11\%/^{\circ}\text{C}$. During this study period (three years) the degradation rate of the panel is $0.041\%/^{\circ}\text{C}$.

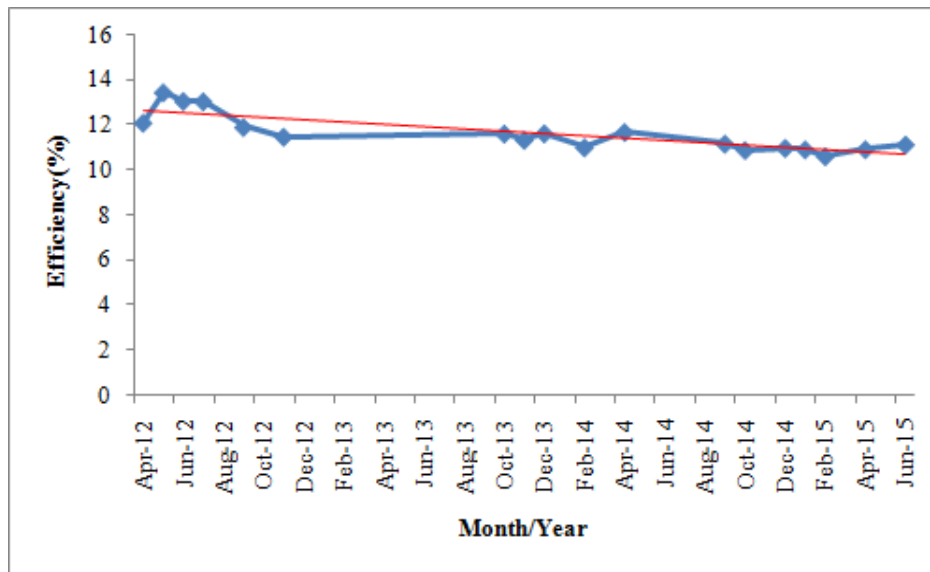


Fig. 2. Variation of Efficiency (%) With Month/Year.

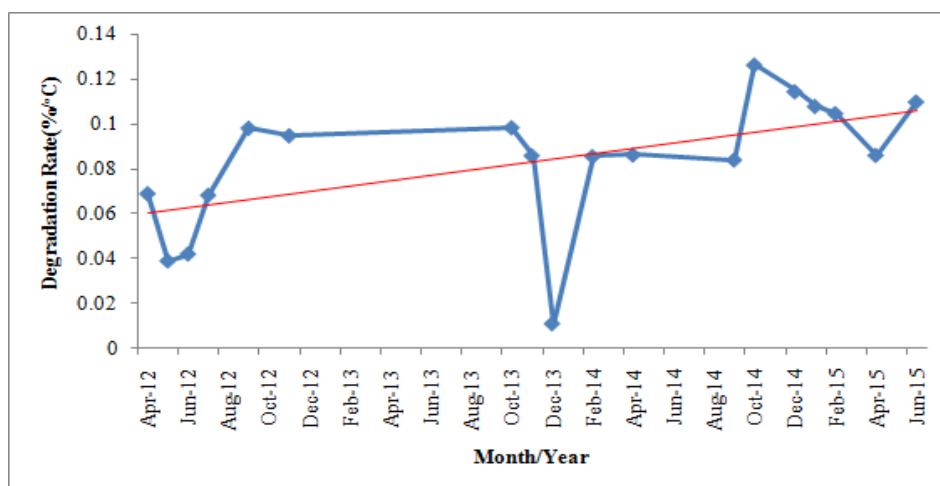


Fig. 3. Variation of Degradation Rate (%/°C) With Month/Year

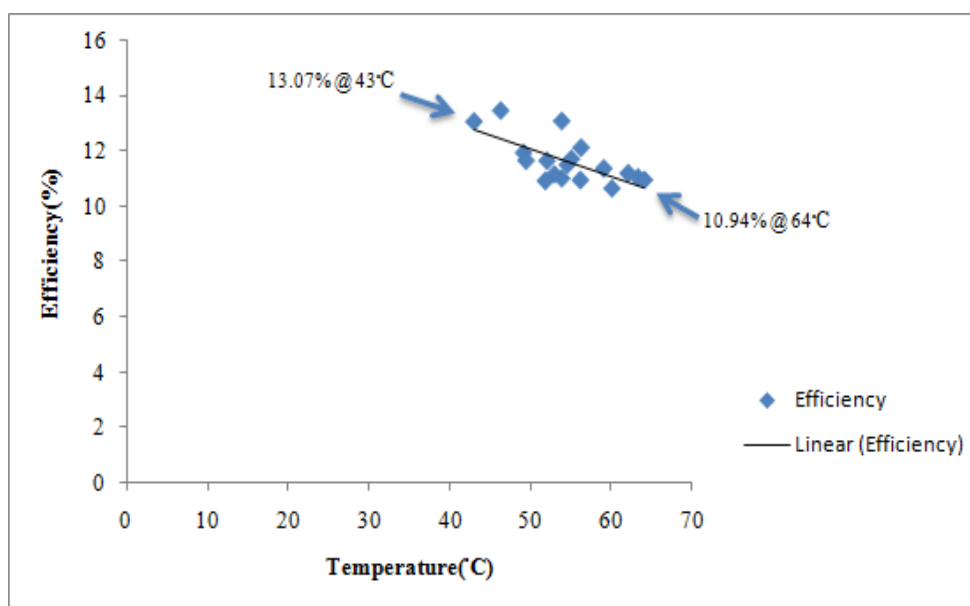


Fig. 4. Variation of Efficiency (%) With temperature (°C)

The Fig.4 clearly explains about the effect the temperature on the efficiency of the panel. The efficiency is proportional to the output power (performance of panel) against input radiation (area of module $\times$ incident irradiance).

By studying the trend it is understood the efficiency decreases as the temperature increases. In this case when the efficiency is 13.07% (the highest

efficiency that has been achieved with panel) the temperature at the same time is recorded as 43°C. At another point when the efficiency is 10.94% (the highest efficiency that has been achieved with panel) and the temperature is 64°C. Therefore for each degree increase in the temperature of the panel 0.08% of the efficiency drops.

CONCLUSION

The main objective of this study is to show relation between temperature, efficiency and degradation rate. In three year study period the performance of the module is analyzed. The efficiency obtained of the module at initial stage is 12.12% and the degradation rate is very less as 0.069%/°C which is negligible. As duration of installation increases the drop in the efficiency is increased with linear increase in degradation rate. According to study

formance is in range and its highest value is recorded as 0.174%/°C. As the Temperature of module increases; the Efficiency of module decreases at that instant and Degradation rate increases. Thus the effect of temperature was studied to estimate the decrease in drop of efficiency.

The majority of solar panels on today's market come with a 25-year long warranty (also known as a performance guarantee). In most cases this means a guaranteed electrical production for 10 years at 90% of rated power output and 25 years at

[5] here the module per-

80% [7]. In this study for first three years average normalized power output of PV module is obtained 85% and performance ratio of the module is 80.34% which clearly indicates that the performance of this PV module is as expected.

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